Arumugam, AK., Fletcher, PN., Nix, AR., Armour, SMD., & Lee, BS. (2002). Scenario driven evaluation and interference mitigation proposals for Bluetooth and high data rate Bluetooth enabled consumer electronic devices. In *IEEE International Conference on Consumer Electronics, 2002 (ICCE 2002)* (Vol. 1, pp. 376 - 377). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/ICCE.2002.1014072

THPM 20.6

SCENARIO DRIVEN EVALUATION AND INTERFERENCE MITIGATION PROPOSALS FOR BLUETOOTH AND HIGH DATA RATE BLUETOOTH ENABLED CONSUMER ELECTRONIC DEVICES

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ABSTRACT

This paper investigates the effects of interference occurring between Bluetooth and high data rate Bluetooth enabled consumer electronic devices in the home and office environment. Software simulated results for frequency collisions between piconets operating in both synchronous and asynchronous modes with typical up and downlink loading factors are presented (for time-bounded and non-time bounded electronic devices). The significance of this interference on the data throughput in a number of example scenarios is investigated using a state-of-the-art indoor space-time propagation model. These results are then compared with measured channel data taken in the test environment using a MEDAV RUSK BRI channel sounder. The paper concludes by proposing to mitigate the effects of interference by employing synchronous communication in future Bluetooth and Bluetooth evolution networks.

INTRODUCTION

Bluetooth is a point-to-point radio standard intended to replace wires and cables in electronic devices. The technology operates in the unlicensed 2.45GHz ISM band and utilises frequency hopping with terminals cycling through 79 1MHz hop channels at 1600 hops/s [1]. Although the current standard is highly desirable for low bit rate applications such as data modems, cordless telephones and low bit rate videophones, it is unable to support high bit rate VCR/TV quality digital video (2-12Mb/s). Previous work has shown that higher data rates can be achieved by employing coherent PSK modulation schemes instead of the current GFSK scheme [2].

In the 2.45GHz band interference can occur due to the coexistence between various wireless devices, such as those based on popular wireless standards like IEEE 802.11b and Home RF. This paper investigates the interference between Bluetooth devices. Assuming a transmit power of 1mW (or 100mW for ranges >10m), frequency collisions between two or more piconets can occur if they operate within close proximity to each other. In addition, since Bluetooth piconets are currently not synchronised, this poses a problem with the number of frequency collisions. This is due to the fact that the data transmissions on the wanted piconet can interfere with the data transmissions on unwanted interfering piconets. Consequently, the requirement to retransmit packets will increase, thus reducing the overall data throughput.

BLUETOOTH FREQUENCY HOPPING KERNEL

The frequency-hopping model used in this investigation follows the 79-hop Bluetooth pattern used in the connection state. The choice of frequencies consists of two parts, i.e. selecting a sequence and then mapping this to the hop sequence. The selection scheme chooses a segment of 32 hops spanning over 64MHz and visits these hops once in a random order. A different 32-hop segment is chosen every time. In the connection state, the Bluetooth device address of the master (24 bits of the lower address part, *LAP* and the 4 least significant bits, *LSB* of the upper address part, *UAP*) as well as the master clock's (*CLK*) 27 most significant bits, *MSB* is used in the hop selection kernel. The frequency-hopping kernel is shown in Figure 1 where signals A to F, X, Y1 and Y2 are defined in Table 1.

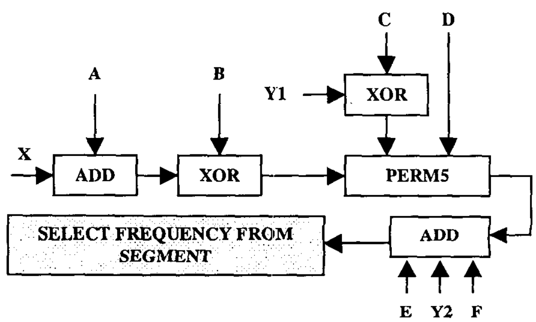

Figure 1: Hop selection kernel for the 79-hop system

Input	Connection State	Number of Bits
X	CLK_{6-2}	5
Y1	CLK_1	1
Y2	$32 \times CLK_1$	1
A	A_{27-23} **XOR** CLK_{25-21}	5
B	A_{22-19}	4
C	$A_{8,6,4,2,0}$ **XOR** CLK_{20-16}	5
D	A_{18-10} **XOR** CLK_{15-7}	9
E	$A_{13,11,9,7,5,3,1}$	7
F	$16 \times CLK_{27-7}$ mod79	7

Table 1: Device address and clock information of the master used for input into the frequency hop kernel

SOFTWARE SIMULATION

The frequency hopping kernel was implemented in Matlab and frequency collision statistics in the connection state obtained for a typical environment containing 2, 3, 4 and 5 piconets. The statistics obtained were computed for Data

0-7803-7300-6/02 $17.00 © 2002 IEEE

Medium (DM1) time slots. The downlink loading factor in the wanted piconet was varied from 10-100%. The unwanted interfering piconets were assumed to be operating within close proximity to the wanted piconet such that any frequency collision between the two would be viewed as interference, thus requiring a retransmission of the corrupted packet. The average uplink and downlink loading factors were varied for the unwanted piconet(s) and collision statistics obtained for both synchronous and asynchronous systems. The piconets are defined as synchronous if the time offset between their hops is less than 259µs (data transmission in DM1 packet occupies 366µs of the 625µs time slot). Figure 2 shows the worst case collision statistics obtained for 3 unwanted piconets (3 interferers) operating in close range to the wanted piconet with a loading factor of 100%.

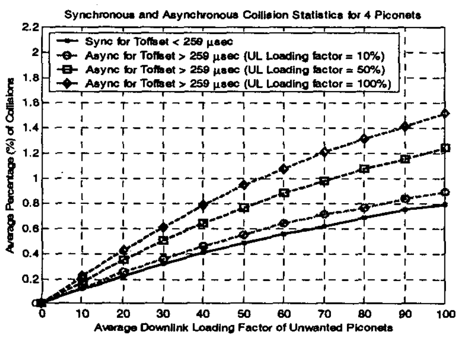

Figure 2: Frequency collision statistics for DM1 time slots in Bluetooth containing 1 wanted and 3 unwanted spatially overlapping piconets with varying loading factors

The frequency collision statistics are highly dependent on the hopping sequence of the individual piconets (which in turn depends on the Bluetooth device address of the master in each piconet). Hence, the above statistics were obtained over an average of 5000 different Bluetooth device addresses for each master, in every piconet. It can be seen that clearly if all the piconets are operating in synchronous mode, the average collisions reduce by as much as half on average since their hops are time synchronised.

INDOOR TEST ENVIRONMENT AND THE PROPAGTION MODELLING TOOL

Based on the collision statistic results, a physical layer link for Bluetooth was developed and used to investigate the Bit Error Rate (BER) and Packet Error Rate (PER) performance for a typical indoor office environment (as shown in Figure 3) with and without the presence of interference. A state-of-the-art indoor propagation modelling tool [3] based on the ray launching technique was used to generate a map of the received signal strength in the environment. Based on the received signal strength and the PER results obtained at different Eb/No values, the maximum data rates achievable were calculated. These results were verified using measured channel data values for the test environment obtained at 2.12GHz using the MEDAV RUSK BRI channel sounder [4]. The data throughput plots were then used to discuss the performance of time-bounded and non-time bounded electronic devices.

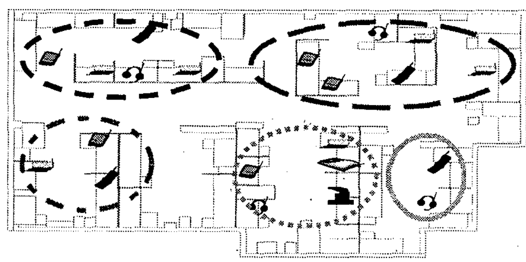

Figure 3: Plan view of a typical office environment (18.5m x 13.8m) containing 5 piconets with consumer electronic devices scattered around

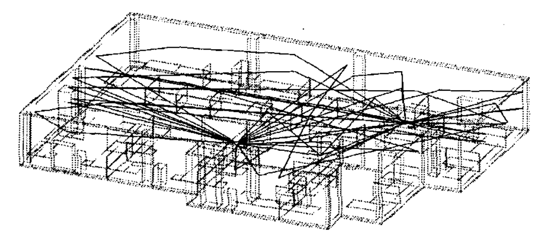

Figure 4: Ray geometry plot for the test indoor office environment

CONCLUSIONS

The frequency collision statistics have shown that a synchronous system is highly favourable for Bluetooth communication in order to reduce the interferences caused by frequency collisions. The final paper will consist of typical scenarios for an indoor home and office environment and the relative performance study of Bluetooth enabled consumer electronic devices for different numbers of interferers and different up and downlink loading factors. The evaluation will cover both asynchronous and synchronous modes and present examples of throughput and coverage in the presence of interference for Data Medium (DM) and Data High (DH) single and multi slot packets.

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